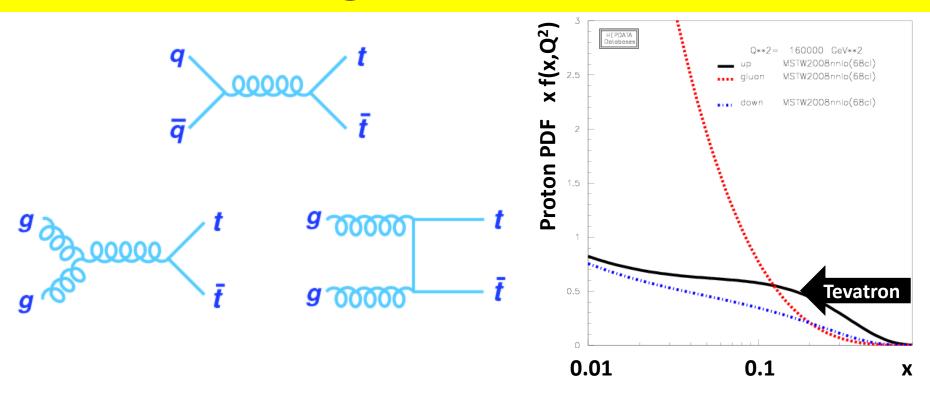
Top quark pair production cross section measurements at CDF & D0



Top at Twenty
Evelyn Thomson

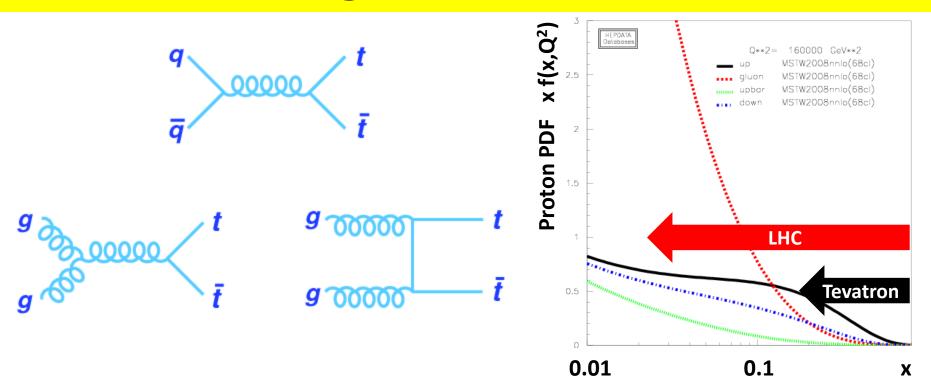
University of Pennsylvania

Strong Pair Production



Tevatron collides 980 GeV beams of protons and anti-protons: minimum x=0.18 so quark anti-quark annihilation dominates [85%]

Strong Pair Production



Tevatron collides 980 GeV beams of protons and anti-protons: minimum x=0.18 so quark anti-quark annihilation dominates [85%] LHC collides 4 TeV (6.5 TeV) beams of protons and protons minimum x=0.043 (0.027), so gluon fusion dominates [above 80%]

Three experimental final states

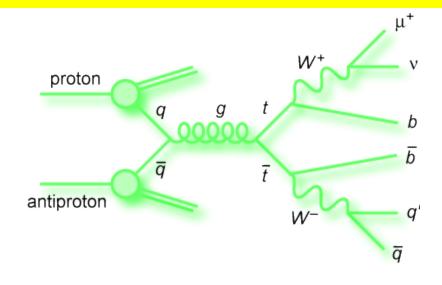
Common feature is two b-jets from weak decays t→Wb

Subsequent decay of W⁺W⁻ bosons gives three final states

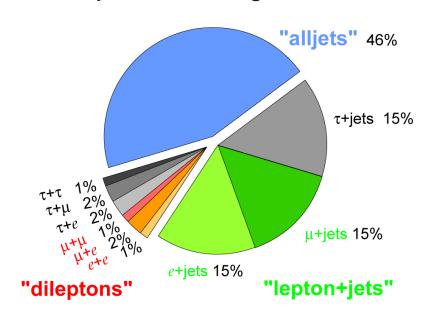
4% dilepton

30% single lepton+jets

46% all jets



Top Pair Branching Fractions



Discovery in 1995 with 50 pb⁻¹

Dilepton and lepton+jets with half of Run 1 data at 1.8 TeV Important features: b-jet identification and unique kinematics Measure inclusive cross section to 30% precision with full Run 1 data

VOLUME 74, NUMBER 14 PHYSICAL REVIEW LETTERS 3 APRIL 1995 Observation of Top Quark Production in pp Collisions with the Collider Detector at Fermilab F. Abe, 14 H. Akimoto, 32 A. Akopian, 27 M. G. Albrow, 7 S. R. Amendolia, 24 D. Amidei, 17 J. Antos, 29 C. Anway-Wiese, 4 S. Aota, 32 G. Apollinari, 27 T. Asakawa, 32 W. Ashmanskas, 15 M. Atac, 7 P. Auchincloss, 26 F. Azfar, 22 P. Azzi-Bacchetta, 21 N. Bacchetta, 21 W. Badgett, 17 S. Bagdasarov, 27 M. W. Bailey, 19 J. Bao, 35 P. de Barbaro, 26 $M_{JJ} = 79 \text{ GeV/c}^2$ Jet 3 W Jet 1 (b) Primary Vertex Secondary Vertices Jet 4 (b)

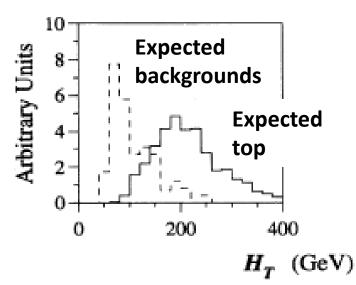
VOLUME 74, NUMBER 14

PHYSICAL REVIEW LETTERS

3 April 1995

Observation of the Top Quark

S. Abachi, ¹² B. Abbott, ³³ M. Abolins, ²³ B. S. Acharya, ⁴⁰ I. Adam, ¹⁰ D. L. Adams, ¹³ M. Adams, ¹⁵ S. Ahn, ¹² H. Aihara, ²⁰ J. Alitti, ³⁶ G. Alvarez, ¹⁶ G. A. Alves, ⁸ E. Amidi, ²⁷ N. Amos, ²² E. W. Anderson, ¹⁷ S. H. Aronson, ² R. Astur, ³⁸ R. E. Avery, ³⁰ A. Badam, ²¹ V. Balamurali, ³⁰ J. Balderston, ¹⁴ B. Baldin, ¹² J. Baldin, ¹² J. Bartlett, ¹² K. Baziz, ²⁷ J. Bendich, ²⁰ J.



Inclusive cross section in Run II

5% precision by combining six measurements from CDF & D0

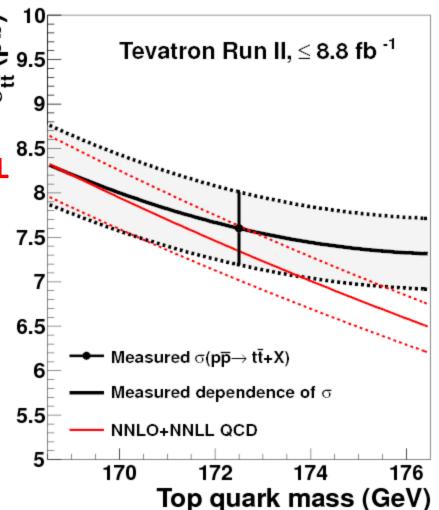
7.60 ± 0.41 pb CDF+D0, PRD 89, 072001 (2014)

4% precision from theory NNLO+NNLL

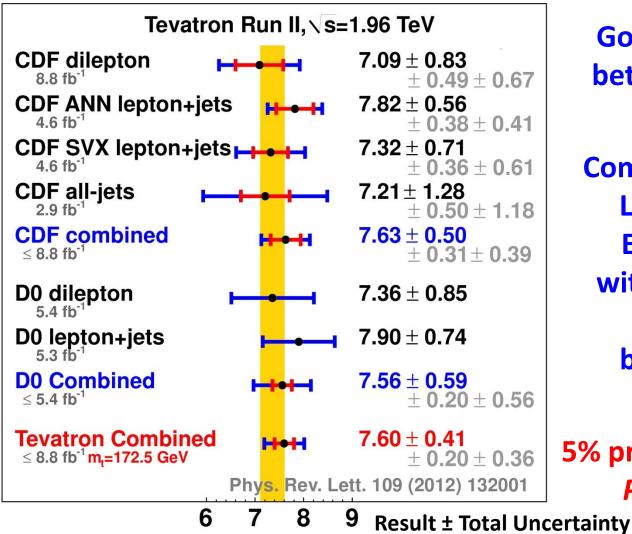
Barnreuther, Czakon & Mitov

PRL 109, 132001 (2012)

Prediction top++ m _{top} = 172.5 GeV	σ (pb)	Δ Scale (pb)	Δ PDF (pb)
NLO+NLL	7.09	+0.28 -0.51	+0.19 -0.13
NNLO+NNLL	7.35	+0.11 -0.21	+0.17 -0.12



Inclusive cross section in Run II



Good agreement between final states

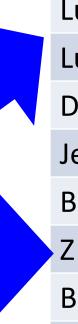
Combine with Best Linear Unbiased **Estimate (BLUE)** with correlations of systematics between results

5% precision CDF+D0, PRD 89, 072001 (2014)

 $\sigma(p\overline{p} \to t\overline{t})$ [pb] **± Stat ± Systematic**

Uncertainties (pb)

D0 optimized technique to reduce statistical uncertainty



Uncertainty (pb)	CDF	D0	Tevatron
Statistics	0.31	0.20	0.20
All systematics	0.39	0.56	0.36
Signal model *	0.21	0.13	0.18
Luminosity (inel)*	0.05	0.30	0.15
Luminosity (det)	0.06	0.35	0.14
Detector model	0.17	0.22	0.13
Jet model	0.21	0.11	0.13
Bkg theory *	0.10	0.08	0.10
Z normalization	0.13	N/A	0.08
Bkg data	0.08	0.06	0.05
Method	0.01	0.07	0.03

CDF reduced 6% luminosity uncertainty to 2% by normalization to Z cross section

D0 Lepton+Jets

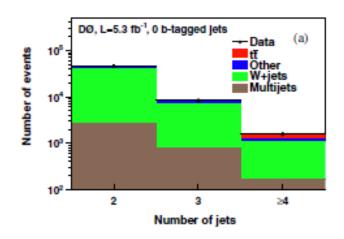
Classify by number of jets and b-tags

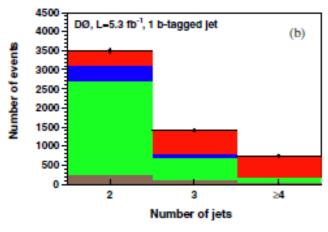
- If dominated by top, then fit number of selected events with estimate of small W+HF backgrounds
- If dominated by background, then fit discriminant based on kinematics

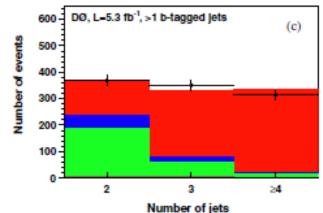
Excellent statistical sensitivity, but more sources of systematic uncertainty with kinematics, b-tagging and W+HF

Can use W+2 jets to fit W+HF fraction (small difference between PRD and PLB)

7.90 ± 0.74 pb combined 5300 pb⁻¹ PRD 84, 012008 & PLB 704, 403 (2011)







D0 Lepton+Jets

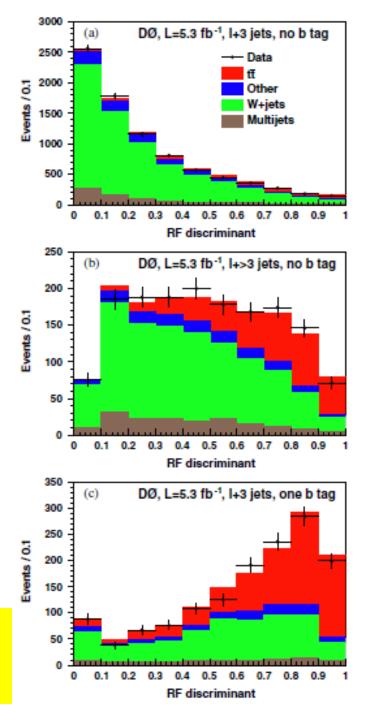
Classify by number of jets and b-tags

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CDF Lepton+Jets

Reduce luminosity uncertainty from 6% to 2% for first time

- Measure ratio of ttbar and Z/γ*
- Normalize to Z/γ* theory

Fit ttbar and W+jets from a discriminant with kinematics

 $7.82 \pm 0.56 \text{ pb}$ 4600 pb⁻¹

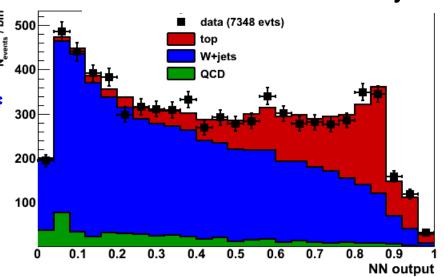
Reduce W+jets background with b-tagging, fit number of events

 $7.32 \pm 0.71 \text{ pb}$ 4300 pb⁻¹

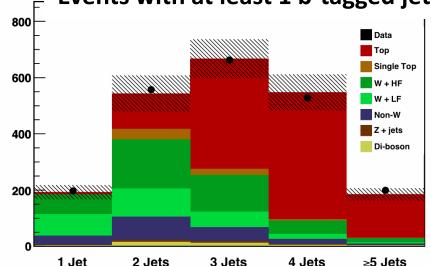
Only 30% statistical correlation since different information used

7.70 ± 0.52 pb combined CDF PRL 105, 012001 (2010)

Discriminant for at least 3 jets



Events with at least 1 b-tagged jet

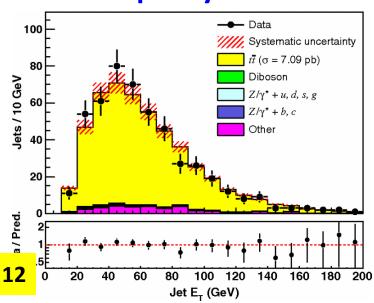


Dilepton & All-jets

7.09 ± 0.83 pb 8800 pb⁻¹ CDF PRD 88, 091103(R) (2013)

Dilepton

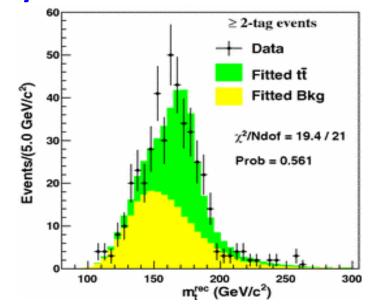
- smallest branching fraction (4%) and low backgrounds
- At least 1 b-tagged jet has 91% purity



7.21 ± 1.28 pb 2900 pb⁻¹ CDF PRD 81, 052011 (2010)

All-jets

- biggest branching fraction (46%) and large backgrounds
- Jet model dominates systematics

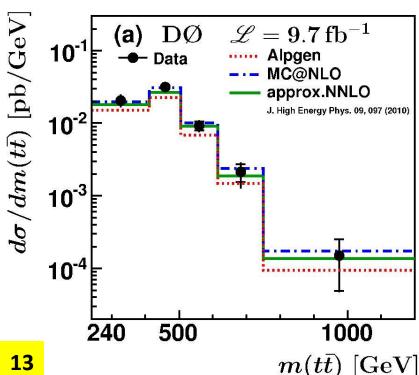


Differential cross section

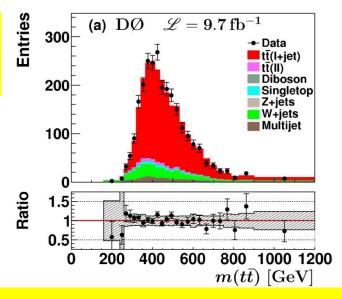
D0 Run II for lepton+jets 9700 pb⁻¹

Test model by Alpgen, MC@NLO and **NNLO** calculations

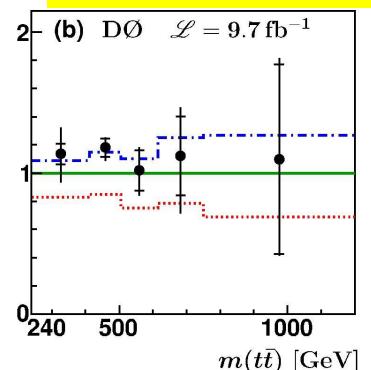
- low acceptance effects (central events)
- good agreement with standard model







DO PRD 90, 092006 (2014)

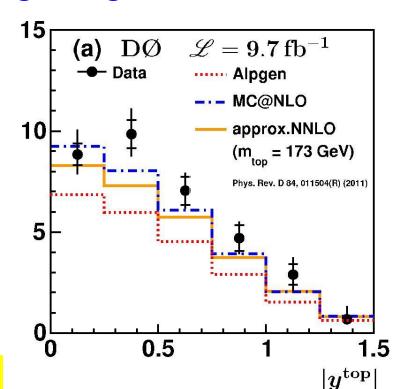


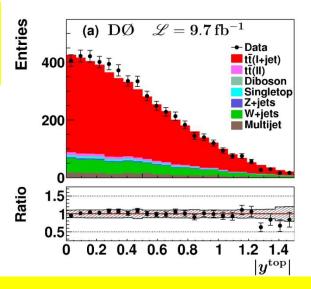
Differential cross section

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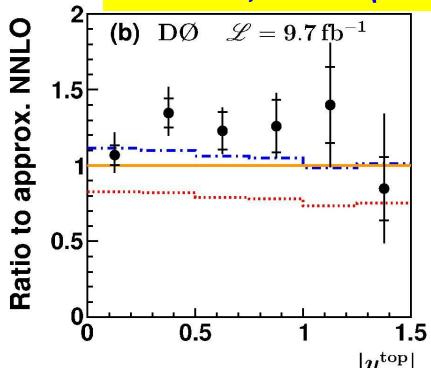
Test model by Alpgen, MC@NLO and NNLO calculations

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- good agreement with standard model





DO PRD 90, 092006 (2014)



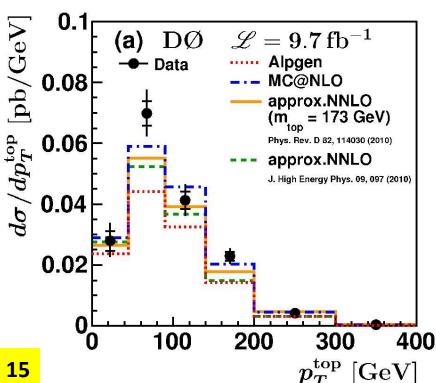
 $d\sigma/d|y^{ ext{top}}|~ ext{[pb]}$

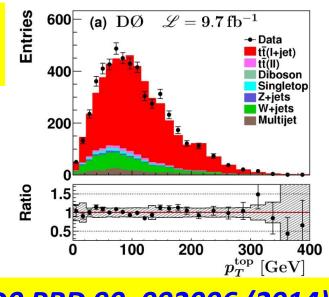
Differential cross section

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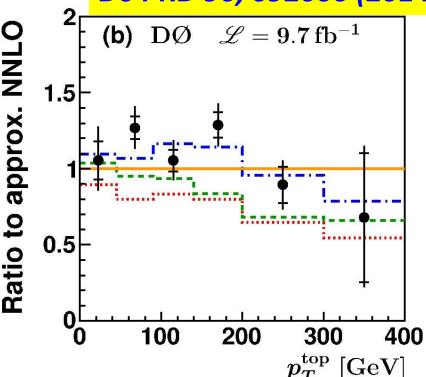
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- low acceptance effects (central events)
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DO PRD 90, 092006 (2014)



Summary

- ✓ Different experimental final states in good agreement with each other
- ✓ Inclusive cross section in good agreement with impressive theoretical predictions
- ✓ Differential cross section with full Run II dataset tests QCD model

